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# DRAG COEFFICIENT VARIATION DURING SPACE TUG AEROBRAKING - CASE 237

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MEMORANDUM FOR FILE

This memorandum responds to a NASA request for information concerning the variation of space tug drag coefficient during the aerobraking portion of the tug flight.

Drag coefficient, for a given configuration, is a function of Reynolds number and Mach number. However, as Reference 1 shows, at higher Mach numbers drag coefficient is essentially constant with increasing Mach number, and mainly varies with Reynolds number. Thus, for the higher speed tug missions, to obtain drag coefficient as a function of altitude, it is only necessary to calculate tug Reynolds number as a function of altitude, and then convert Reynolds number to drag coefficient by an experimentally derived relationship.

The tug used for calculations is the hemisphere-cylinder described in Reference 2. It has a diameter of 14 feet, and an entry velocity of 33,800 ft/sec.

Reynolds number is written as

$$Re = \frac{\rho V D}{\mu} \qquad (1$$

where $\rho$ is the atmospheric density, V is vehicle velocity, D is a characteristic vehicle dimension, and $\mu$ is atmosphere viscosity.

In equation (1), D is taken as 14 feet, V is taken as 30,000 ft/sec (to an accuracy of $\pm$ 15%, according to Reference 2), and $\rho$ may be taken as $(.109)e^{-\frac{Z}{22,000}}$ lbs/ft$^3$ (Z is altitude) with an accuracy of ~50% (Reference 3). With these substitutions, equation (1) becomes



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$$Re = 5.2\ 10^9 e^{-\frac{Z}{22,000}} \quad (2)$$

which is accurate within a factor of two.

The attached figure, taken from Reference 1, is a plot of drag coefficient $C_D$ vs free-stream Reynolds number $Re_\infty$ for a sphere. It is assumed to be similar to the $C_D$ - $Re_\infty$ curve for a hemisphere-cylinder at small or zero angle of attack. The altitudes corresponding to Reynolds numbers were determined by the relationship of equation (2) and are also plotted on the abcissa.

While it is important to know drag coefficients accurately in the flight regime from atmospheric entry (400,000 ft altitude) to tug periapsis, the main region where errors in knowledge of drag coefficient could significantly affect the mission is bounded by periapsis as a lower limit and two scale heights above periapsis[2] (~50,000 ft) as an upper limit. Changes in drag coefficient in this region will now be discussed.

The tug with L/D = 0.3 has a periapsis altitude of 186,000 feet. Figure 1 shows that for the critical region 186,000→236,000 feet, the Reynolds number varies from $10^6 \rightarrow 10^5$, and $C_D$ is essentially constant at 0.9.

The ballistic tug, L/D = 0.0, has a periapsis altitude of 205,000 feet. In its critical region of 205,000→255,000 feet, Reynolds number varies form $3 \cdot 10^5 \rightarrow 3 \cdot 10^4$, and $C_D$ ranges from 0.9→0.92.

Finally, for the negative lift mode, L/D = -0.3, where periapsis altitude is 225,000 feet, Reynolds number varies from $2 \cdot 10^5 \rightarrow 2 \cdot 10^4$ as the critical region ranges from 225,000→275,000 feet, and produces a $C_D$ variation from 0.9→0.93.

Thus, for the hemisphere-cylinder tug aerobraking in a single atmospheric pass, the drag coefficient in the high deceleration regime is essentially constant. At higher altitudes, where deceleration is substantially less, $C_D$ increases to a maximum value of ~1.6 at atmospheric entry. If the ballistic coefficient of the tug were lowered, and deceleration occurred at higher altitudes, then variation in drag coefficient would become more pronounced in the critical region.

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1013-RNK-ajj R. N. Kostoff

## REFERENCES


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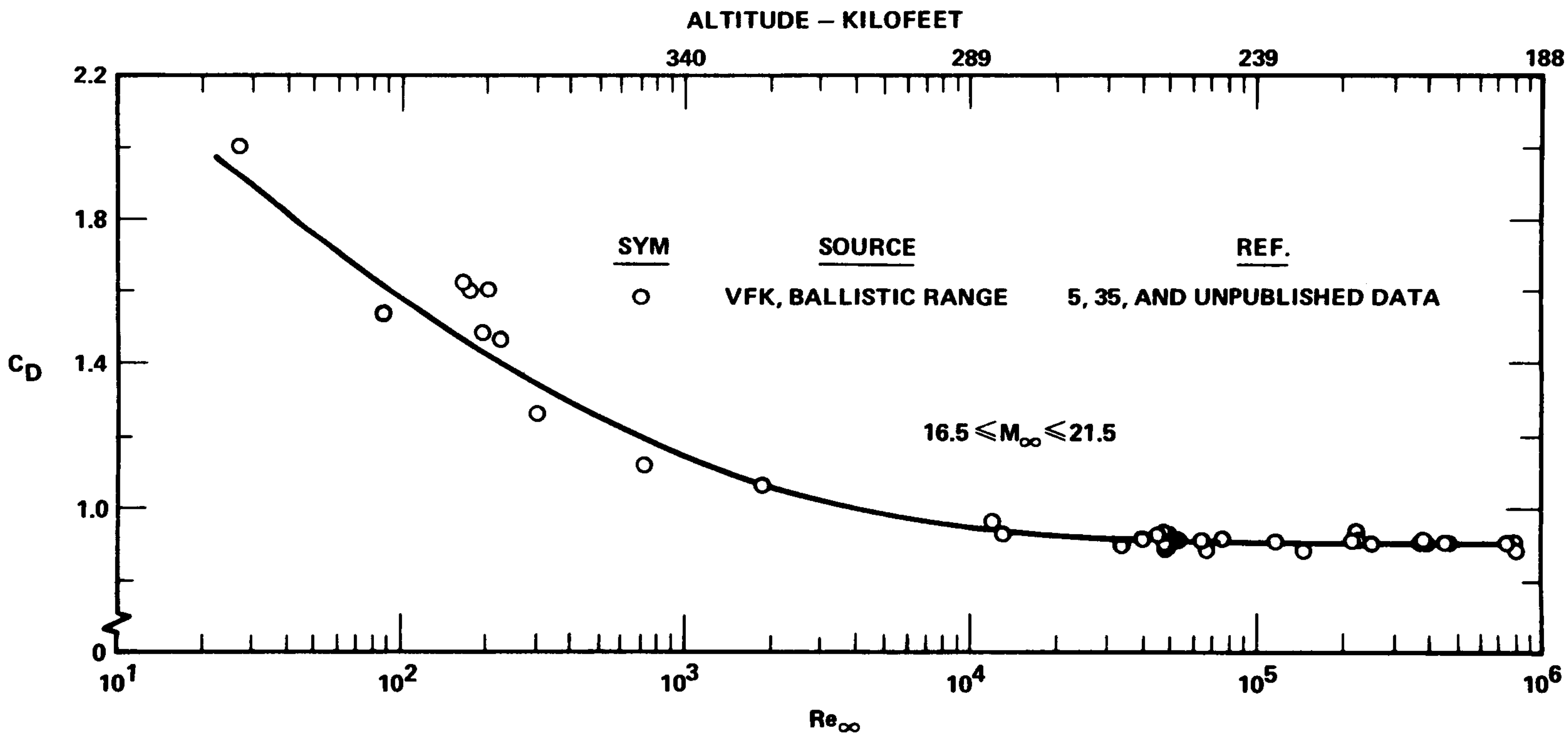
ALTITUDE – KILOFEET
340
289
239
188
2.2
1.8
1.4
1.0
0
$C_D$
SYM
SOURCE
REF.
VFK, BALLISTIC RANGE
5, 35, AND UNPUBLISHED DATA
$16.5 \leq M_\infty \leq 21.5$
$10^1$
$10^2$
$10^3$
$10^4$
$10^5$
$10^6$
$Re_\infty$

FIGURE 1